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ABSTRACT

One area explored in the second (in-depth) phase of the Learning in Science Project was "children's science," defined as views of the world and the meanings for words that children have and bring with them to science lessons. The inquiry reported focuses on problems/difficulties of learning about the concept of "force" through analysis and comparison of the nature and place of this concept in both "children's science" and "scientist's science." Data were obtained by the "interview-about-instances" procedure in which students were shown diagrams on cards which represented different instances (exemplars) and non-instances (non-exemplars) of the concept. The first section considers children's views of forces, analyzing them in terms of some common aspects of children's science identified from a variety of studies. These studies indicate that children are influenced by everyday use of the word and tend to have a human-centered view of the world and endow objects with human characteristics or endow abstract ideas with an almost material existence. The second section considers how a scientist's conception of force differs from that understood by children, followed by views of students who have been taught physics (including 100 college students). Interview cards used and a summary of other studies on force are included in appendices. (JN)

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LEARNING IN SCIENCE PROJECT

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FORCE

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WORKING PAPER No. 16

In our view successful science teaching requires an appreciation not only of the scientists' view of the world, but also an appreciation of the language, the beliefs and the expectations which children bring with them to science classes. This working paper has developed from a study carried out in the in-depth phase of the Learning in Science Project and is one of a series of papers which explores aspects of Children's Science (see Working Paper No. 14). It is our hope that these papers portray children's views of the world and meanings for words in a way which will be useful to teachers and to curriculum developers.

In the action-research phase of the project it is our intention to attempt to build practical and useful teaching strategies based on the findings of the in-depth phase of the project. For this reason we are actively seeking comments on the findings we have detailed, and seeking information on the variety of ways teachers develop ideas associated with the topic under focus in this paper.

We would be grateful if comment and/or information could be forwarded to

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University of Waikato,
Private Bag,
HAMILTON.

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FORCE

A working paper of the Learning in Science Project

Roger Osborne

August 1980

INTRODUCTION

"Many times my physicist friends have attempted to explain a concept to me and, in their exasperation, have tried one explanation after another, each one of which sounded (to me) abstract, difficult to grasp, and generally abstruse. When I could comprehend, at last, what they were trying to communicate inevitably I was surprised to discover that the idea was actually quite simple". (Zukav, 1979, p.24)

Undoubtedly some of the very basic ideas in physics seem to cause great problems for pupils trying to learn science. To physicists, the scientific concept of force is a simple idea and one of central importance in understanding how and why things behave as they do. Yet to the learner of science, it is not simple at all.

"The only thing we had which I didn't really understand was the physics sort of things ... you know, like the ball rolling up the hill and coming down again ... I just sort of got lost". (ex-pupil)

Sometimes it is not simple to the teachers either!

"The topic forces is sort of covered (by us) but if you asked a physicist to look at what concepts were developed I am not sure he would say that they are very good at all". (intermediate school teacher)

And it certainly isn't easy to teach in the opinion of a number of teachers. For example,

"I feel I need time and resource materials and help from a physics minded person to help with that particular topic ... especially at the Form 3 level ... It is trying to get it across in a simple enough way that they would understand it and enjoy it". (secondary teacher)

Even when the teaching is finished it is not always clear what they have learnt,

"I sometimes wonder how much is being attained in understanding what forces are ... It is difficult to know whether kids are understanding them or not". (secondary teacher)

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In Working Paper No. 14 "Reconsidering the Framework" the distinction was made between scientists' science and children's science, and the teaching and learning of science were seen as the process of modifying children's science toward scientists' science. This paper considers the application of these ideas to the problems and difficulties of learning about 'force' through an analysis of the nature and place of force in children's science and through an analysis of the nature and place of force in scientists' science. By a comparison of these two perspectives we hope to perceive more clearly the bridge which we need to help pupils construct, so that they can move more easily from one perspective to the other.

FORCE AND CHILDREN'S SCIENCE

Working Paper No. 3 "Focus on Knowledge" detailed some findings about student's meanings of the word force. This perspective of force was established using the interview-about-instances method (Osborne and Gilbert, 1979) using the instances detailed in Appendix A. The students analyzed held a wide range of views about force and children had strong views about the meaning of the word force from an early age.[1]

In this section we will consider those views of force which might best be considered as children's science; those views of the world and meanings for words that children hold before being formally taught science. Moreover, we will analyze children's views in terms of some common aspects of children's science which have been identified from a variety of studies.[2] As with all concepts we have studied, children's science is found to be a viewpoint not exclusively held by children who have not been formally taught science and examples provided by older children are also given.

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[1] 38 children were interviewed initially. There were 7 children aged approximately 9 years, 9 children aged 11 years (Form I), 10 children aged 13 years (Form III), 5 fifth form children (aged 15 years) all enrolled in a School Certificate science course, and 7 second year Teachers College students aged approximately 19 years. 19(SC), 19(UE), and 19(B) indicates students who had been taught science to school certificate, physics to university entrance, or physics to bursary level respectively.

[2] The interview-about-instances technique has been used with a variety of concepts (friction, gravity, animal, plant, living, light, electric current) and an associated technique called interview-about-events has been used to investigate students' views of physical and chemical change.

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The word force, while having a technical meaning in physics is used in a variety of ways in everyday language. Firstly, as an organized body of people. Only once in the set of interviews was it used in this way.

"No ... there is a force on the policeman but not on the demonstrator because of police force". (Police, 11)[3]

Secondly, it was more commonly used by children as a verb. For example,

"Yes, because he is being forced to do something". (Police, 9,11,11,13)

"Yes, because he is forcing him to move". (Police, 11,13,13,19(SC),19(SC))

"Yes, he is forcing the car". (Car I, 9,11,13,13,13)

"Yes, he is trying to force it to go". (Car I, 11,11,19(SC))

"No, he is not really forcing it, he is more just pushing it". (Car II, 11,13)

This everyday use of the word force as a verb, to force, is very much related to human experience and consists of two distinct types, physical contact and mental coersion. The instances and the associated questions were quite commonly considered by children from this human-centred viewpoint. Examples are

"Only if he was fighting (or struggling)". (Police, 9,11)

"If he was doing something wrong". (Police, 9,11)

"No, he is just relaxing". (Police, 9)

"Yes, he is going without his will". (Police, 13,13,13,13)

"Oh, he would be arguing at the car ... kicking it ... then he would probably start walking ... he would do a force if it was a brand new car (why?) well he would probably wave out to another car that passes by ... try to save his car instead of leaving it out". (Car I, 13)

"No, (there is no force on the car) cause it is moving and it is really a force on the man cause he has got to push it". (Car II, 11)

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[3] Name denotes instance, see Appendix A. Numbers denote age(s) of children with that view.

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This human-centred view was particularly common with the accelerating car instance (Car II) even though the diagram did not show the driver.

"Yes, the man is putting a force on the car". (Car II, 9,9,9,13)

"Yes, the man is forcing it to go faster". (Car II, 11,11)

"Yes, there is a force on the pedal of the accelerator". (Car II, 13, 13,13,19(SC))

"No, because no one has to push it". (Car II, 9,11,11)

These everyday language and human-centred viewpoints are closely related to the view that if there is no obvious external agency forcing the body then there is no force on the body.

"No ... if the bike is slowing down on its own accord ... there is not really any force required at all". (Bike, 13)

"No, not really because he is not pedalling or anything". (Bike, 9,11, 11,11,13)

"No, it is kind of natural". (Bike, 13)

"No, it's just dropping freely". (Golf II, 7,9,11,11,13,13,13)

"No, because if it is dropped ... nothing is helping it ... it just goes plonck by itself". (Golf II, 11)

"No, because boxes are square and sometimes they get stuck". (Box, 9)

"No, it just naturally rolls down". (Ball, 13)

Another aspect of the human-centred viewpoint is the idea that something that can't be observed or felt by humans (or animals) doesn't exist. This latter view is quite commonly held by children and it has been particularly noticeable with respect to some concepts we have studied, e.g. electric current and light. Further examples, of a slightly different nature, are,

"No, because it can't feel anything ... but there is a force on the man because he has to push it and that puts a force on him". (Car I, 9)

"No, the golf ball can't feel anything ... it is just made". (Golf, 9)

"I don't know, the car has not got a brain on anything". (Car I, 11)

"I would not think so because in the moon movies that I see they just jump up in the air and land 20-30 feet away from where they are". (Moon, 11)

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In a number of concepts that we have studied children not only often have rather human-centred or even self-centred viewpoints, but also they attribute many of the characteristics of humans or animals to non-living things - for example, forcing oneself to do something. Endowing objects with human or animal characteristics is seen in many examples;

"Yes, it is forcing itself to stop". (Bike, 9)

"I suppose there is a bit of force because it has got to force itself to stay up". (Box, 9)

"I don't know if it is forcing itself". (Ball, 9)

Occasionally we got examples of one inanimate object forcing another.

"Yes, it is forced to go faster by the slope of the hill". (Ball, 11,13,15)

Related to this viewpoint is the idea that forcing oneself to do something requires action. Thus it is not surprising to find that many children endow moving objects with a force. For example,

"Yes, the speed that he has already got up". (Bike, 19(0))

and the negative examples,

"No, it is not moving". (Car I, 7)

"No, because he cannot get it to move". (Car I, 11)

Moreover, as with other concepts, we found examples of the abstract idea being treated as if it had material existence; the force is somehow imbedded in the moving object,

"It is just putting force on by itself ... from the force you gave it before". (Bike, 9)

"Yes, because the man would be hitting (the ball) and there would be a force on the ball (which) would be getting less as it goes up". (Golf I, 9,9,9,11,11,11,13,15)

"I suppose there is because the force from the hit is still on it". (Golf I, 13,13,15)

"The force from the hit is still ... it would stop if it wasn't there". (Golf I, 13,15)

"The force from when the bowler let it go would still be inside it ... it has not finished". (Bowl, 19(DE), 19(SC))

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The various views discussed above, while exemplified from the force interviews, are not exclusive to this one concept. Our studies over a variety of concepts show that children are often influenced by the everyday use of the word, in this case force; they tend to have a rather human-centred view of the world, they tend to endow objects with human characteristics; and they tend to endow abstract ideas with an almost material existence. However, it should be pointed out that any one child is not exclusively influenced by one or any of these viewpoints. Different instances tend to evoke different viewpoints.

In addition to the above quotes, which we have seen can be classified in terms of viewpoints which are common across a variety of concepts, there were some views which were more specific to the concept of force alone. One noticeable aspect of this was the fact that some children considered that more non-observable forces on some objects were due to the presence of air. For example,

"Yes, the wind is forcing it up". (Golf I, 11)

"The force of the air making it come down". (Golf II, 19(SC))

"The atmosphere pushes things down". (Ball, 13)

"The only thing I can think of is the air type thingy behind it making it speed up because of the tilt of the hill". (Ball, 19(SC))

"There is no gravity ... he is out of the atmosphere". (Satellite, 11,13,19)

"Gravity is the pull of the air ... take away the air and there would by no gravity". (Moon, 13)

Finally, approximately 30% of those school children interviewed had a viewpoint which was reasonably consistent with intuitive scientific ideas of a force, namely a push or a pull. This viewpoint can be included here under children's science as it was a view held by some younger children as well as older children. That is, some children hold this view before being taught any physics.

"Yes, because the man is pushing the car". (Car I, 9,11,13,13,15, 15,15,19(SC),19(B))

"Yes, because something is trying to slow it down ... because something is pushing it the other way it slows down". (Bike, 9,10,15)

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"Yes, the force of gravity and possibly air". (Golf II, 9,11,15,19(SC))

"Yes, because of the moon's gravity". (Moon, 9,11,11.11,15,15,15,19(S), 19(B))

FORCE AND SCIENTIST'S SCIENCE

Let us now turn to scientists' science and see how the idea of force as understood by physicists differs from the idea as understood by children.

To a physicist the idea of a force is not bound up with living things, or with the transference of the attributes of living things to inanimate objects, as is found to some extent in children's science. The clear difference between the physicist's view and the children's view in this regard is that to a physicist a force acts on objects (living and non-living) rather than being contained within objects. Basically to a physicist 'force' is a noun and simplistically forces are synonomous with pushes or pulls. If you push on a car you put a force on the car - "apply a force to the car" - not in the sense of giving it a mysterious something but simply in the sense of the noun push - the "act of pushing". If you pull on a car, then there is a force on the car simply in the sense of the act of pulling. If a golf ball is hit from a tree there is a force on the ball while the club head and ball are in contact. No force is transferred to the ball. Once the hit is finished and the ball leaves the club there is no force on the ball, or in the ball, from the hit as the club no longer pushes on the ball.

If all pushes and pulls involved contact, so that the object producing the push or pull was clearly apparent, then it would perhaps be not too difficult for children to understand the physicists' idea of a force. However, unfortunately many forces are very mysterious to everyone, including physicists, in that pushes and pulls can occur without contact. The earth pulls all other objects towards it but even physicists don't know how this occurs - the force of gravity is a mystery. As we have seen some children assume the air provides the force of gravity - perhaps to some this solves the mystery by providing a contact force. Unfortunately, in reality, if the air is removed the force of gravity remains: any two masses, even in a vacuum, attract each other.

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To some extent physicists have stopped concerning themselves too much about what forces, like the force of gravity or the force of friction, actually are. Rather they find it useful to consider them as rather mysterious pushes and pulls, and to concern themselves more with measuring the strength of these pushes and pulls. This they can do by measuring what effect a push or a pull has on an object. Let us consider this further.

In many situations, there are a number of pushes or pulls acting on an object at the same time. Taking the example of a book on a table, there is the pull of gravity downwards - physicists would consider this to be one force on the book. There is also an equal and opposite force produced by the table pushing up on the book - physicists call this force a reaction force. It is not a friction force although children sometimes call it that. Physicists would say that the total force acting on the book is zero. In fact they find it is useful to use this idea as a measure of force viz if an object is at rest (for more than an instance) then the total force acting on it is zero.[4] What is a much more difficult idea to understand - and this is where scientists' science differs considerably from children's science - is that an object moving at a steady speed in a straight line has a total force acting on the object which is zero. This is difficult for children to understand partly because they often have the idea that a moving object has a force in it and partly because in their experience all the moving objects that they are familiar with appear to require a force acting on them to keep them moving at a steady speed. However a spacecraft needs no pushing to keep it moving through space at a steady speed. An ice puck needs no pushing, once it has been pushed by the ice hockey stick, to keep it moving in a straight line. From a physicists' viewpoint a box sliding on a surface needs a steady push to keep it moving, at a steady speed, not because the force inside it is wearing out and needs to be replaced as some children view it, but rather to balance out the force of friction which is pushing in the opposite direction. In fact again physicists use this idea to measure forces; namely if an object is moving at a steady speed (including zero speed) then the total force acting on it is zero. Alternatively if the total force is not zero on an object, then it will be changing speed (e.g. an apple falling) or changing the direction of the speed (e.g. an apple whirled around your head on the end of a string) or both.

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[4] A ball thrown upwards may be at rest for an instance at the top of its flight. However, there is still the pull of gravity on it, and the total force on it is not zero.

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In summary, a force to a physicist is simply a push or a pull which acts on a body. If the total force acting on a body is not zero, then the body will speed up or change the direction in which it moving.[5] In Appendix A the instances considered in the interviews are analyzed from a physicists' point of view to provide further clarity. Finally Warren (1979) in a very good book details some of the more advanced ideas needed to teach force at the senior physics level.

FORCE AND VIEWS OF STUDENTS WHO HAVE BEEN TAUGHT PHYSICS

Now that we have compared and contrasted children's views and physicists' views about force, let us now consider the views of students who have been taught some physics. In addition to the original 38 interviews, some five of which involved students who had studied physics at the sixth or seventh form level, approximately 100 first year University physics students were asked for their responses to the four instances CAR, BIKE, GOLF I and MOON as used in the original interviews. This latter group represents a relatively homogenous sample of reasonably well motivated and intelligent students who had been exposed to formal instruction in physics.

The University students were questioned collectively in a lecture at the beginning of the year and were asked to give written responses to the 'interviewers' questions on a sheet provided.[6] Of the students approximately 80% had sat Bursary Physics, the remainder had at least Univeristy Entrance by accreditation.[7]

Approximately 10% of the University students gave what might be considered very good answers from a physicists' point of view. They analyzed the situation in terms of the effect of the force on the motion of the body and distinguished between the total force and the individual forces acting on the body. Another 45% of students gave adequate answers. While their answers may not have been complete in a physics sense, there was no indication that their views were incompatible with the accepted scientific viewpoint.

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[5] From this physicists define what they mean by force. If a body of known mass has an acceleration, then by definition the total force acting on the body is given by the product of the mass and the acceleration.

[6] The students' sheet also had copies of the line drawings depicted.

[7] Responses of these students are flagged by 18, their average age, and B or UE for Bursary or UE Physics. 18(B65) denotes a first year physics student who gained 65 in Bursary Physics.

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A further 30% of the University students gave answers which did indicate some scientifically unacceptable use of language and/or physical understanding. Finally some 15% of the students provided at least one response that could be properly classified in terms of the children's across-concepts-viewpoints detailed in the first section of this paper under children's science.

Examples of students, who had been taught sixth or seventh form physics, giving answers which can be best understood in terms of children's science have already been given in the first section of this paper. One of the most common examples of this is the idea that force is contained within a body.

> "There is a force because of the bike's own mass ... the mass of the bike has come to such a speed that it won't just stop straight away ... the force is still in there ... in the bike ... the force was transferred from the person pedalling ... and it is now still adherent in the bike ... the bike still moves forward". (Bike, 19(D))

The language of the above quote is much more sophisticated than that used by the younger children but the idea is very much one from children's science.

With regard to students who have been taught some physics it is possible to find incorrect use of scientific terms. To a physicist kinetic energy and momentum are not alternatives to the word force. Force acts on a body but kinetic energy and momentum are properties associated with a body. Thus the physicists' view of kinetic energy and momentum are similar to the children's view of force in that they are considered as properties of the body. Not surprisingly therefore, students can be found who confuse these terms. For example,

> "The wind as well as the kinetic energy from the golf club". (Golf 1, 19(UE))

> "Yes, there is initial energy transferred to the ball". (Golf 1, 19(UE))

The force of gravity is undoubtedly something which causes great difficulty to many students learning physics.[8] Some students appear to accept it as a force because they have been told it, but they can't really accept it, possibly because of the non-contact nature of the force.

[8] We are continuing our investigations of the nature of children's understandings of gravity and frictional forces and these will be the subject of a separate paper.

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"I can't explain that, apart from gravity I suppose helping it to go down ... I think of it as a force because (people) say the force of gravity but it is a pull rather than a push and I think of a force as a push rather than a pull". (Bail, 15)

"(Is gravity a force?) Oh, I suppose it is but I don't see it as a force". (Colf II, 13,13)

The possibly related idea, that the force of gravity is provided by the air, is one we have found is still held by a few first year University physics students.

The learning of knowledge about force without the analysis of a student's children's science viewpoint sometimes leads to self contradictory views. For example some students, despite the fact that they considered that an absence of air meant that there was no gravity acting on a satellite, considered that there was gravity on the moon and that there was also no air on the moon. Others had scientifically confused ideas about weight and gravity. While to a physicist, weight is simply the force of gravity, this is not so to all students.

"No, because there is no gravity on the moon ... but there is weight ... they use heavy shoes to weigh him down". (Moon, 15(0), 19,19(0))

"His weight is pushing him down ... (but) there is no gravity on the moon". (Moon, 13)

The idea of no gravity on the moon was held by 4 of the 100 first year University physics students, in addition to 5 of the 15 and 19 year olds who had been interviewed.

"No, gravity is lacking on the moon". (Moon, 18(B57))

"(There is) little or no gravitational force on the moon". (Moon, 18(B55))

"No, there is no gravitational force on the moon". (Moon, 18(B51))

In summary what can be said about force and the views of students who have been taught science. Firstly it should be said that there are students who have acquired a sound scientific view of the meaning of force. On the other hand some students do have views which can be related to non scientific views found in younger children and it would appear that these students have failed to learn and appreciate the scientists' view of force, sometimes despite considerable exposure to formal teaching of physics. Undoubtedly, the scientists' concept of force is difficult to teach and to learn.

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WHERE DO WE GO FROM HERE?

In summary there are considerable differences between a child's view of force and a physicist's view of force. Also students in science classes hold ideas about 'force' which range from ideas similar to those held by young children to ideas which are very similar to those held by physicists. If the methods we have used to portray students' views are valid then we would suggest that there are considerable difficulties in the teaching of the physicists' views about force. It is not a uniquely New Zealand difficulty; the student views we have described are supported by the work of other overseas who have attempted to portray students ideas about force. Some aspects of their work and its relationship to our work is mentioned briefly in Appendix B.

This paper has been written to share our thinking with others. The questions remains 'Can the information found in this paper be used to devise strategies to enable the physicists' view of force to be taught more effectively? Does the information in this paper make you as a teacher want to stop teaching 'force', start teaching 'force' by a new method, or carry on teaching 'force' in the way you have been doing it? If so can you analyze why you have been influenced or uninfluenced in this way?

As we consider the work to be done in the action-research phase of the Learning in Science Project we find we need to consider questions like

i) is it dangerous or desirable to expose children to other children's views irrespective of whether these views are scientifically acceptable or not;

ii) is it desirable in teaching to deliberately compare and contrast the range of views held by children with the views held by physicists (presented at a suitable level!)

iii) would it be appropriate or useful to explain to children how these different viewpoints have arisen, and why and how the physicists' ideas can be useful?

As always your comments would be appreciated.

ACKNOWLEDGEMENTS

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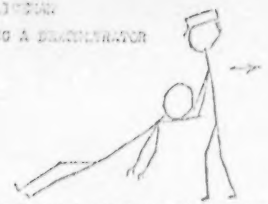
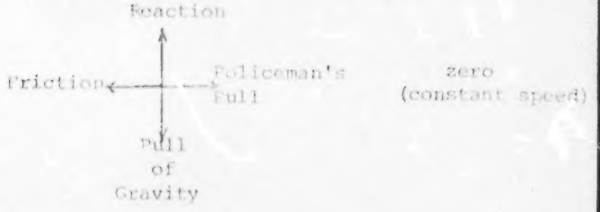
(direction and strength)

POLICE

A POLICEMAN
PUSHING A DEMONSTRATOR



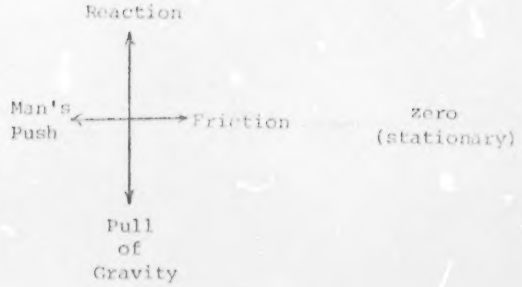
IS THERE A FORCE ON THE DEMONSTRATOR ?



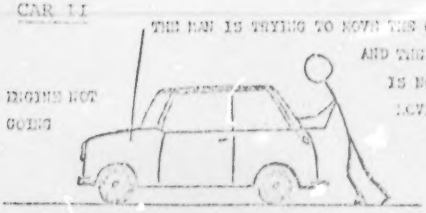
CAR I

THE MAN IS TRYING TO MOVE THE CAR BUT
THE CAR IS NOT MOVING

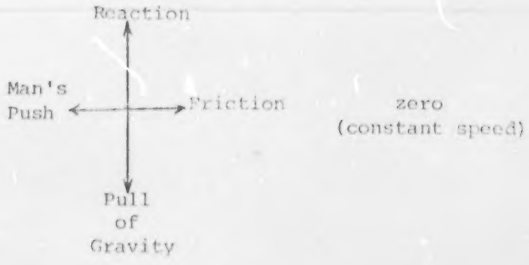
IS THERE A FORCE ON THE CAR ?



CAR II

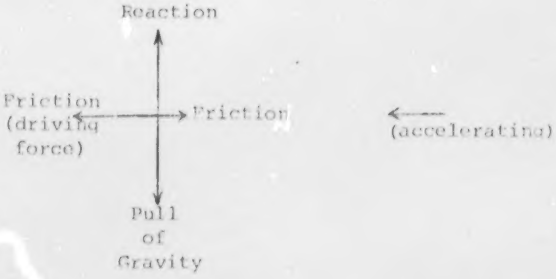


IS THERE A FORCE ON THE CAR ?

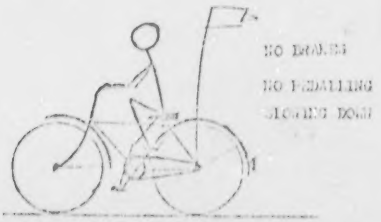


CAR III

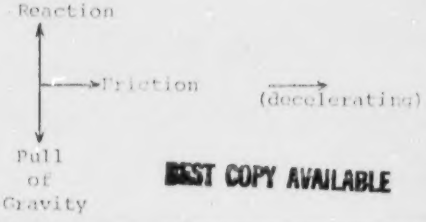
IS THERE A FORCE ON THE CAR ?



BIKE



IS THERE A FORCE ON THE BIKE ?



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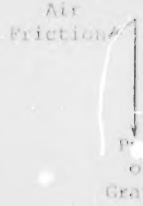
GOLF I

IS THERE A FORCE ON THE GOLF BALL ?

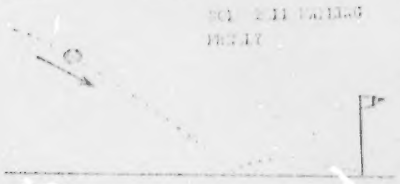
Individual Forces (direction and strength)



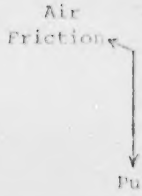
Total (or net) Force

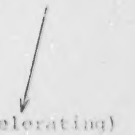
(accelerating)

GOLF II



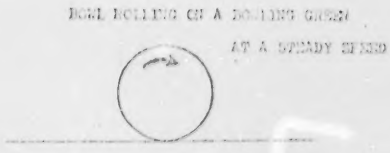
IS THERE A FORCE ON THE GOLF BALL ?





(accelerating)

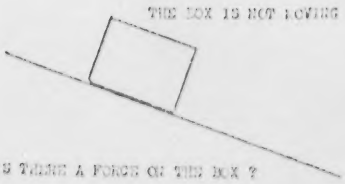
BOWL



IS THERE A FORCE ON THE BALL ?

zero (steady speed)

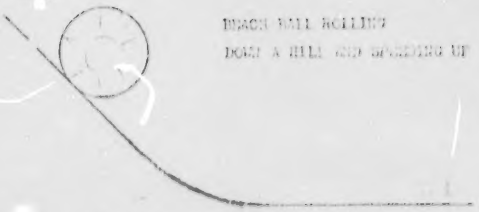
BOX



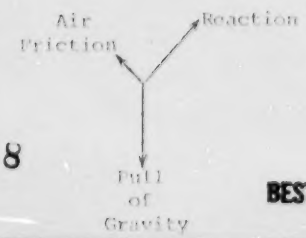
IS THERE A FORCE ON THE BOX ?

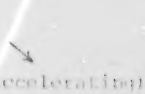
zero (stationary)

BALL



IS THERE A FORCE ON THE BEACH BALL ?





(accelerating)

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THE INTERVIEW CARDS

THE PHYSICIST'S VIEW

Individual Forces (direction and strength) — Total (or net) force

CUSHION

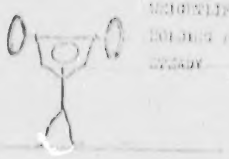
IS THERE A FORCE ON THE CUSHION ?

Reaction

Pull of Gravity

zero (stationary)

WEIGHTLIFTER



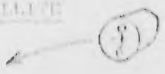
IS THERE A FORCE ON THE BAR ?

Reaction

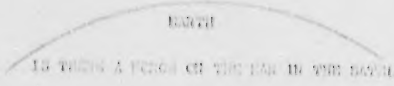
Pull of Gravity

zero (stationary)

SATELLITE



BAR IN A SATELLITE GOING AROUND THE EARTH



IS THERE A FORCE ON THE BAR IN THE SATELLITE ?

Pull of Gravity

(accelerating)

MOON

MAN STANDING ON THE MOON

IS THERE A FORCE ON THE MAN ?

Reaction

Pull of Gravity

zero (stationary)

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APPENDIX B

OTHER STUDIES ON FORCE

Undoubtedly the study most similar to the work described in this paper is the work of Watts (1980). Watts working in the U.K., has a similar philosophical perspective to that used in this study, and like this study his work builds out of the earlier work of Osborne and Gilbert (1979). Watts uses the same interview-about-instances technique but with different cards to those used in the Learning in Science Project. In reporting his findings, Watts (1980) states the children commonly associate force with movement and states that few students recognize force in stationary objects. As in our study, almost no students discussed the instances in terms of mass and acceleration. Watts also identifies the problem students have with non-contact forces, and suggests that apart from the use of force in the societal sense of compulsion to do something, contact was necessary for forces to act. He also comments on the tendency of younger children to use anthropomorphism and animism. With regard to older children he comments on the confusion between force, energy and momentum. In some associated interviews on energy he found that energy was considered by some children to act on objects rather than be a property related to an object. In summary the work of Watts validates and reinforces the views discussed in this working paper.[a]

The work of Viennot (1979) in Paris was concerned with the views students at the first year University and senior secondary school levels have about force. She states,

> "We all share a common explanatory scheme of 'intuitive physics' which although we were not taught it at school, represents a common self-consistent stock of concepts and which, however wrong it may be, resists attempts to change or modify it. This 'intuitive physics' presents at the very least, a considerable challenge to teaching. Also, it makes much of our teaching less effective than we usually assume it to be". (Viennot, 1979, p.205)

[a] Particularly as his paper was received just as we were completing this paper.

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Viennot comments on the 'intuitive' law that velocity and force are closely related.[10] She also comments on students who consider 'the force in a body keeps it moving' and of the confusion and lack of distinction in some children's minds between force and kinetic energy. From her work, which primarily involved paper and pencil tests, two general tendencies of students with regard to 'intuitive' or spontaneous reasoning were noted. These were

(i) the tendency to attribute physical quantities (e.g. a force or energy) to objects themselves,

(ii) the tendency to look for a force (or feel the need for a force) in the direction of motion in order to account for the motion.

Viennot has not explored children's science as such, but her work on students' science very much compliments the work we have done in this area.

Other studies include those of Piaget (1929) whose results are child centred. However, he studied concepts such as force not so much for themselves but to illustrate intellectual growth. Leboutet-Barrel (1976) has also studied concepts of mechanics held by young people and reviews related studies that had been done up to that time. In particular they re-emphasize the tenacity and resistance to extinction of earlier ideas.

Finally mention should be made of Warren (1979). Warren is very much concerned with misconception in the teaching, as well as the learning, of physics at the senior secondary and lower tertiary levels. He concludes

> "The idea of force is of very great importance in elementary science, engineering and mathematics. It is obviously very widely misunderstood, not only be students but also by highly qualified, mature adults. It is very hard to assess how intrinsically difficult the idea is, since it has been made very much more difficult in practice by the almost incredible confusion of (teaching) approach which has continued unchecked by any action by any professional body. Paradoxically, if we were generally to recognize that it is difficult and were to teach it accordingly, the subject would become more easy". (Warren, 1979, p.45)

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[10] She suggests the intuitive law can be expressed as a pseudo-linear relationship $\underline{F} = k\underline{v}$.

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